



Federal Agency for  
Cartography and Geodesy



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# Earth rotation parameters estimated from combined GNSS and VLBI data and its impact on satellite orbits

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(2) Federal Office of Topography (swisstopo, Wabern, Switzerland)

(3) Astronomical Institute of the University of Bern (AIUB, Bern, Switzerland)

# Motivation for a combined ERP product

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ERP	GNSS	VLBI INT	VLBI R1/R4	SLR
dUT1	-	✓	✓	-
LOD	✓	-	✓	✓
Polar motion	✓	-	✓	✓

Techniques' contributions to Earth Rotation Parameters (ERP)


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## Benefits of multi-technique combination

- **GNSS + VLBI INT** → daily resolution and shorter latency of a consistent set of all ERPs
- multi-day combination → stabilization of ERP

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- stable contribution of LOD from **SLR** → improvement of ERP

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Techniques' contributions to Earth Rotation Parameters (ERP)

## Current ERP daily combination


- combination at **parameter level**

@ IERS RS/PC → IERS-14-C04

@ IERS EOP PC → IERS-Bulletin-A



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Techniques' contributions to Earth Rotation Parameters (ERP)

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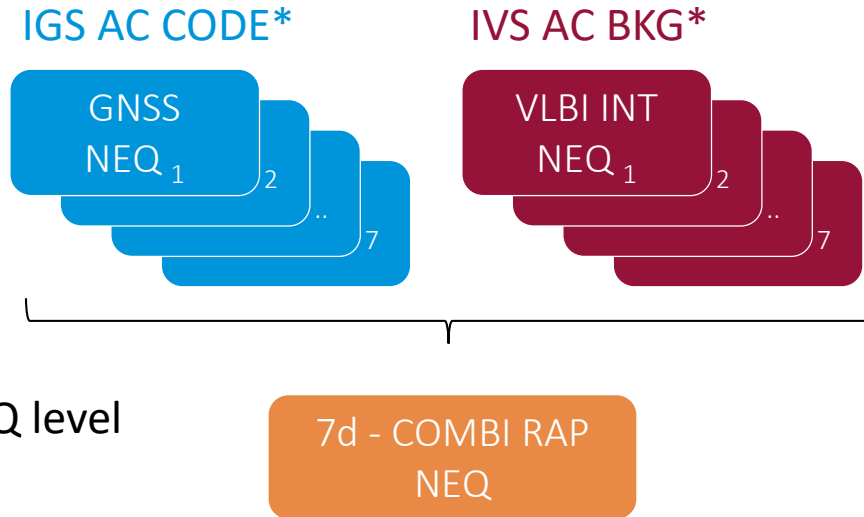
@ IERS EOP PC → IERS-Bulletin-A

## Benefits of combination at **NEQ level (SINEX)**

- considers correlations
- consistent set of parameters
- assures same underlying reference frame
- (positive) impact on other technique-specific parameters

# New BKG ERP product under development

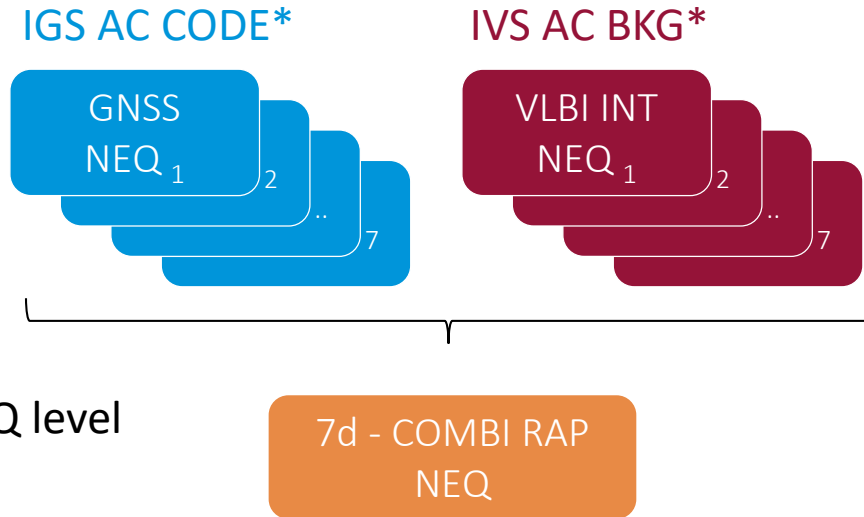
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- Derived from combination at NEQ level
- Using NEQ from SINEX files

- \* official GNSS rapid solution from IGS Analysis Center "CODE"
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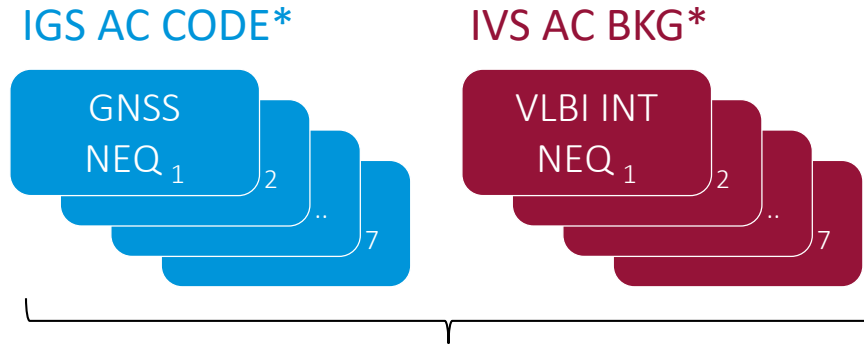
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**CODE = Center for Orbit Determination in Europe**, a consortium of

- Astronomical Institute of the University of Bern (AIUB, Bern, Switzerland)
- Swiss Federal Office of Topography (swisstopo, Wabern, Switzerland)
- Federal Agency for Cartography and Geodesy (BKG, Frankfurt a. M., Germany)
- Institut für Astronomische und Physikalische Geodäsie, Technische Universität München (IAPG/TUM, Munich, Germany)

**IGS AC CODE is operated by AIUB**, using the Bernese GNSS Software

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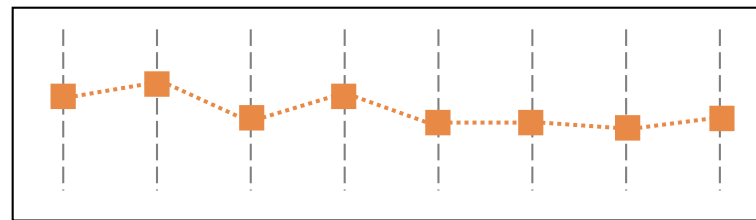


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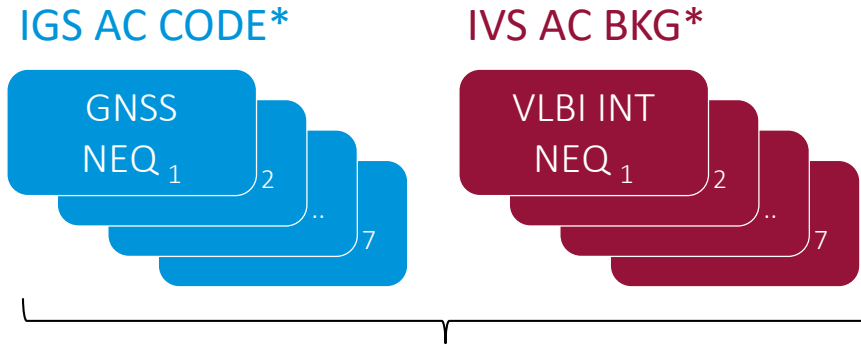
- Derived from combination at NEQ level
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- Best ERP result:  
7-day piecewise linear polygon

7d - COMBI RAP  
NEQ



BKG ERP Product

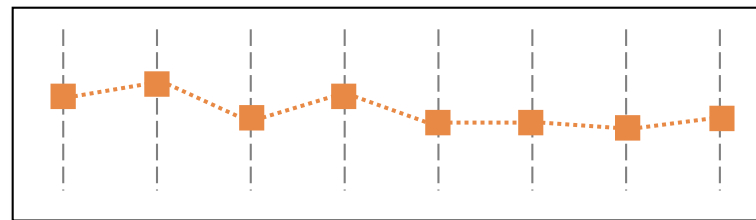
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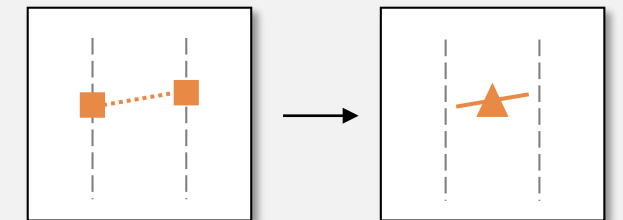
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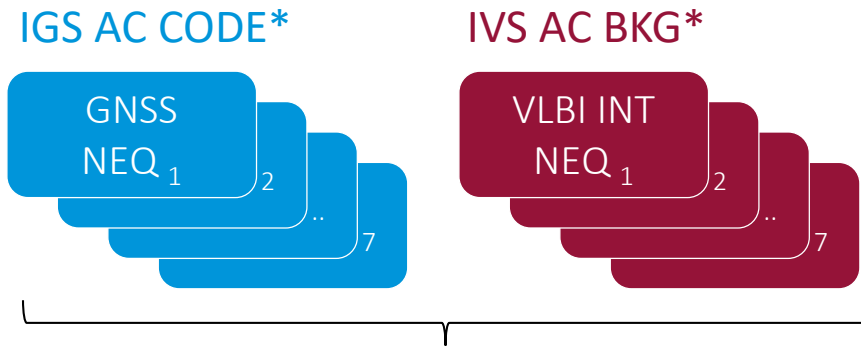
dUT1 parameter representation contains LOD implicitly



2 piecewise linear offsets

offset + drift

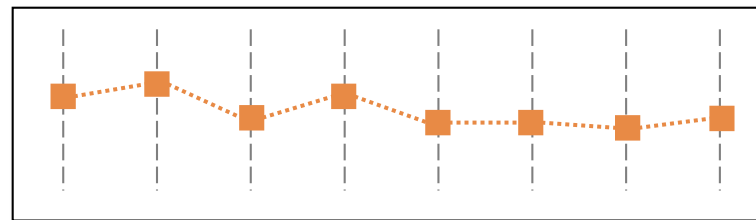
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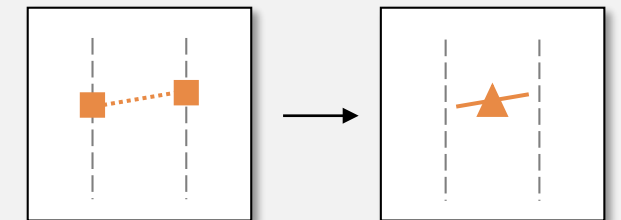
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Lengert L, Thaller D, Flohrer C, Hellmers H, Girdiuk A (2021):  
*Combination of GNSS and VLBI data for consistent estimation of Earth Rotation Parameters.*  
*Proceedings of the 25th European VLBI Group for Geodesy and Astrometry Working Meeting (EVGA 2021).* (eds. R. Haas). ISBN: 978-91-88041-41-8.  
[https://www.oso.chalmers.se/evga/25\\_EVGA\\_2021\\_Cyberspace.pdf](https://www.oso.chalmers.se/evga/25_EVGA_2021_Cyberspace.pdf)

# ERP product validation – OPTION 1



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Compare ERP product w.r.t. external reference

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Reference series: IERS-Bulletin-A, IERS-14-C04, ..

Validation epoch: 12:00 UTC, middle of VLBI observation epoch, ..

ERP product: different solutions A, B, C (technique, arc-length, ..)

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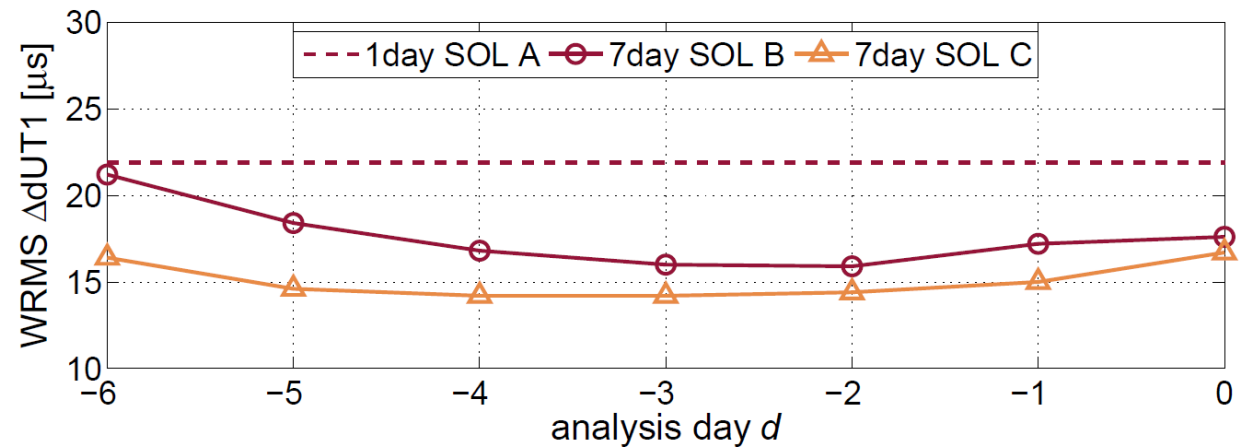
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ERP product: different solutions A, B, C (technique, arc-length, ..)

### Analyse WRMS of ERP differences

- absolute value → depends on the reference
- relative value → shows improvement, but also w.r.t. reference
- reference ≠ “truth”



# ERP product validation – OPTION 2

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Check impact on other parameter from same solution

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Why to look at orbits?

GNSS orbits still have some deficiencies

- .. Solar radiation pressure modelling
- .. CODE estimates 3-day arcs
- .. LOD bias exists, but not understood

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Potential answers:

- Improved orbits
- No impact
- Worse orbits



# ERP product validation – impact on orbits

Overview of estimated parameters in combined solution

# ERP product validation – impact on orbits

## Overview of estimated parameters in combined solution

### Combined NEQ (7 days)

GNSS Rapid - CODE

VLBI INT - BKG

IGS station coordinates

IVS station coordinates

ERP

- Pole coordinates
- dUT1 (piecewise linear offsets)

Orbits

- Keplerian elements
- Dynamical parameter
- Stochastic pulses

Troposphere

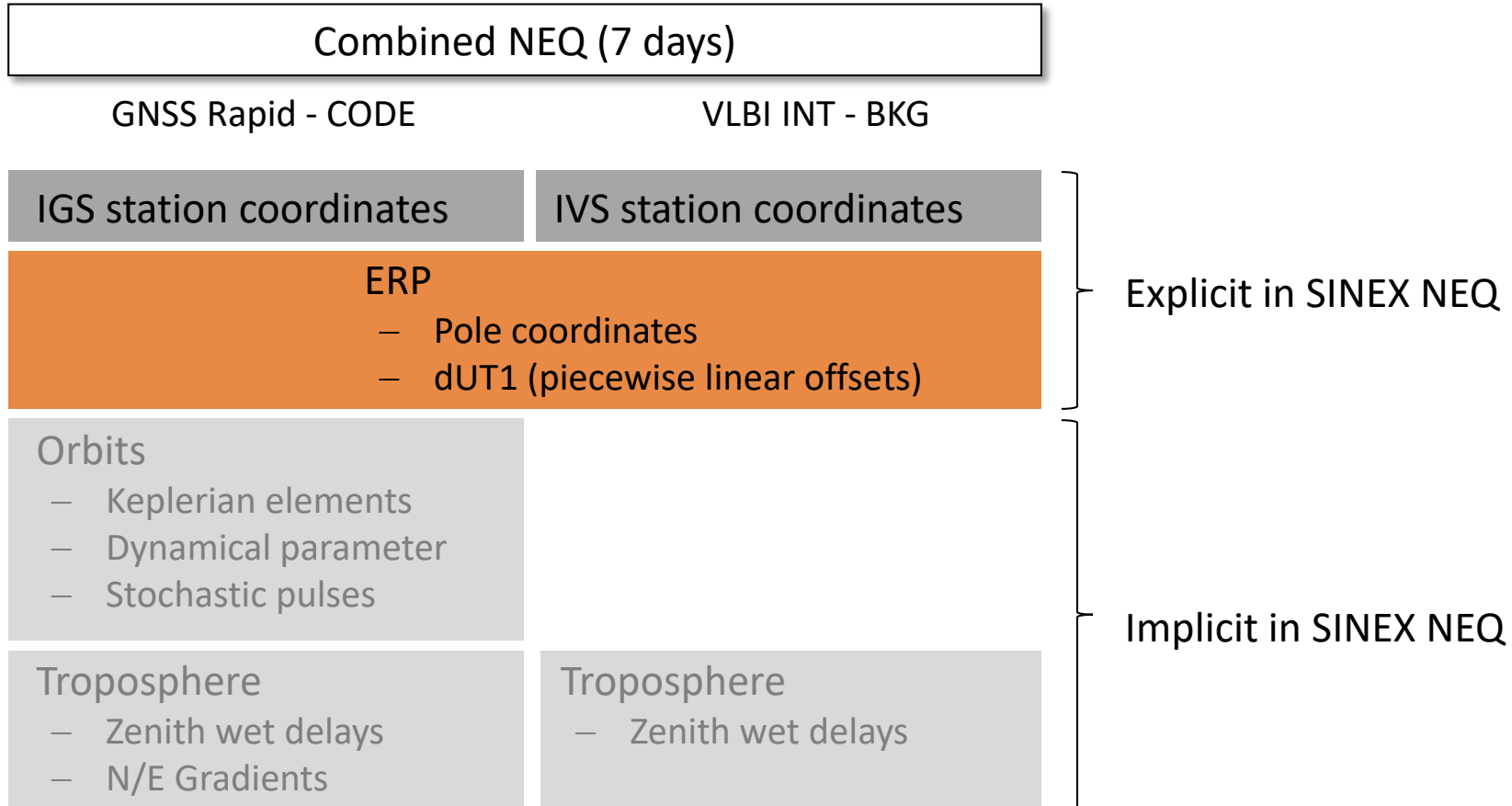
- Zenith wet delays
- N/E Gradients

Troposphere

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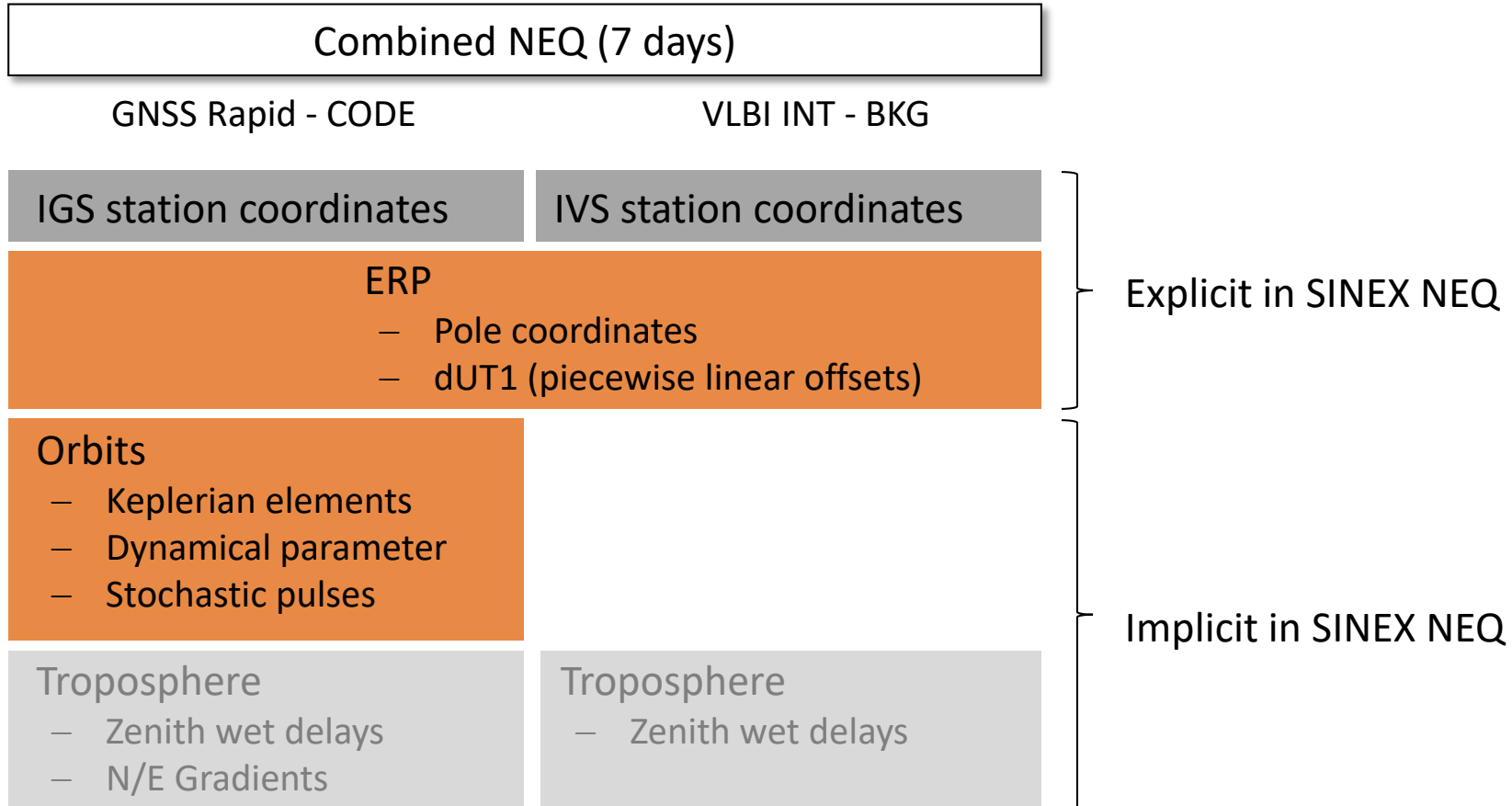
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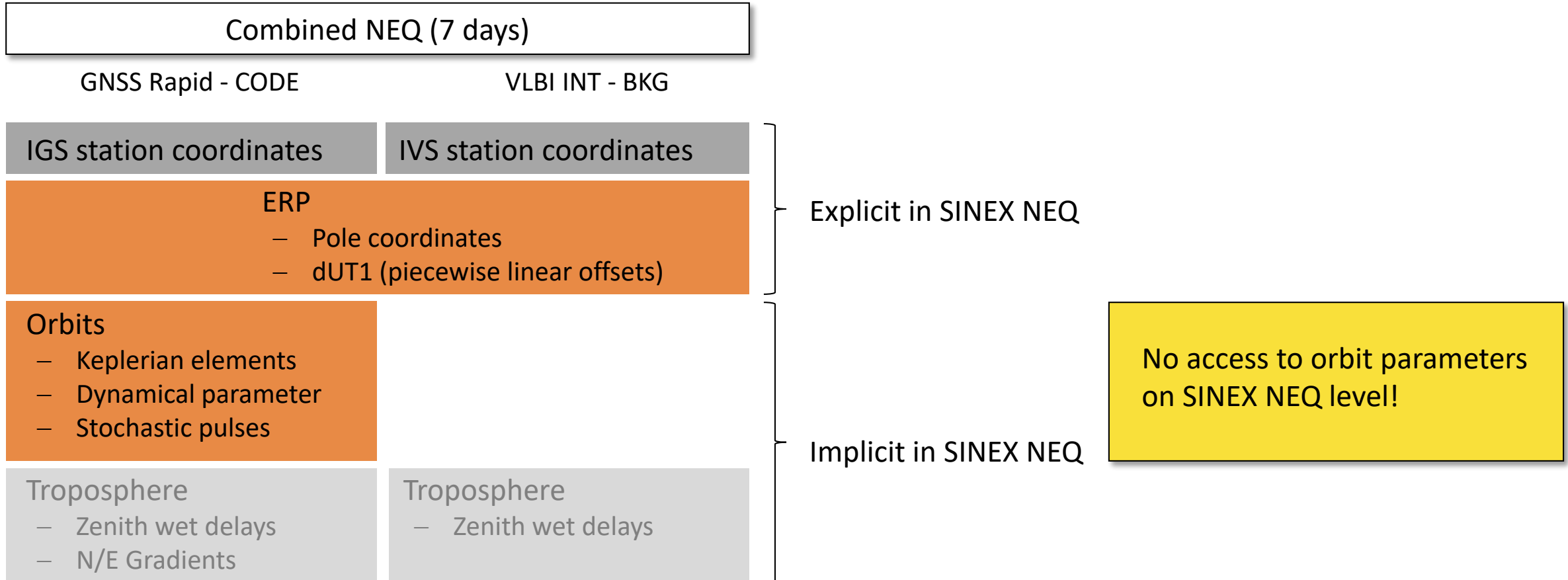
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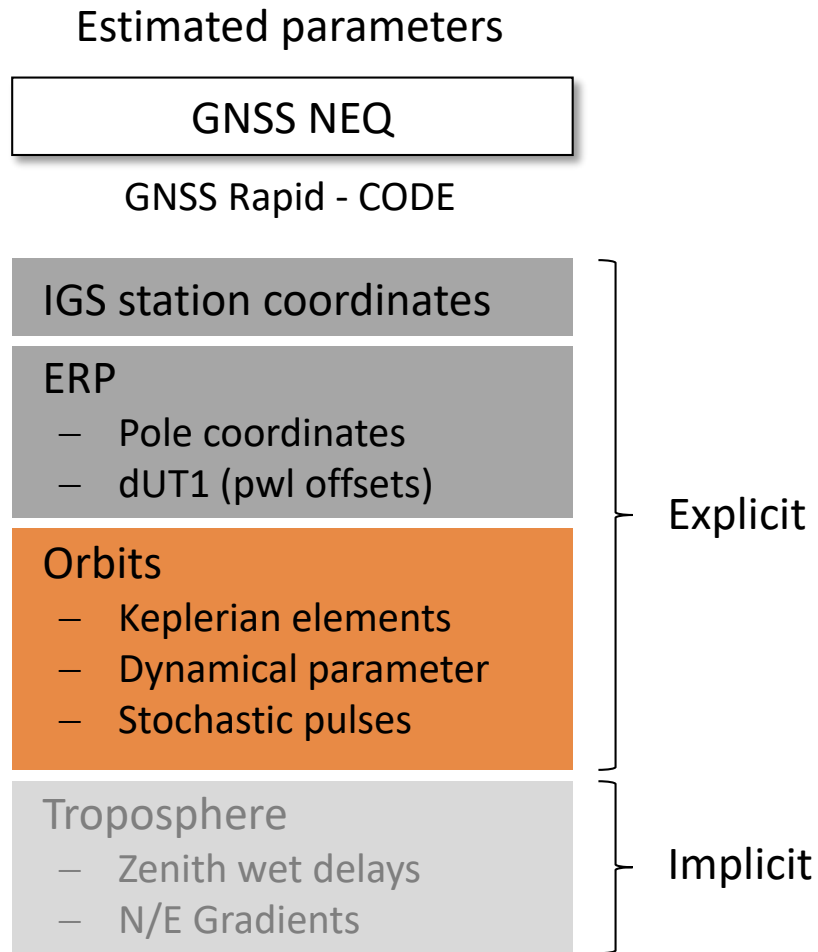


# ERP product validation – impact on orbits

## Overview of estimated parameters in combined solution



# ERP product validation – impact on orbits



Get access to orbit parameters from combined analysis by

- Re-running GNSS Rapid solution from CODE
- Using NEQs provided by CODE (containing orbits as explicit parameters)

# ERP product validation – impact on orbits

## Estimated parameters

GNSS NEQ

GNSS Rapid - CODE

IGS station coordinates

ERP

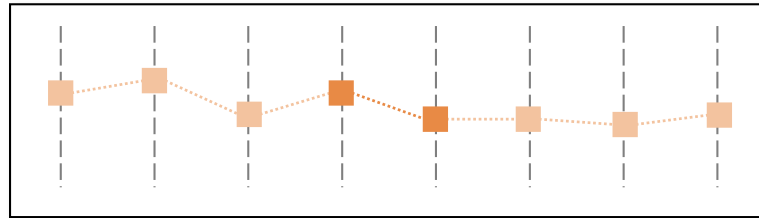
- Pole coordinates
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Get access to orbit parameters from combined analysis by

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- Introducing combined ERP product and fixing all dUT1 values

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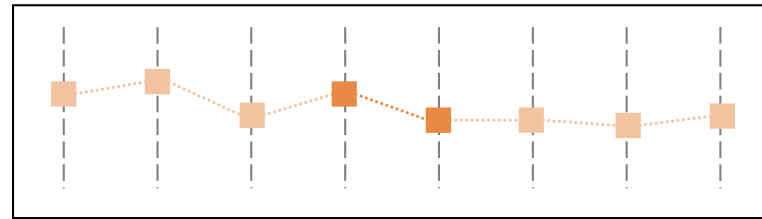
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BKG  
solution

BKG

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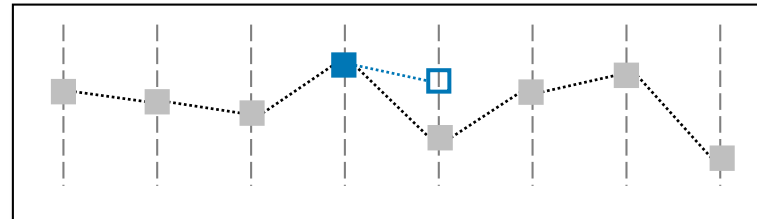
- Pole coordinates
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Troposphere

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Reference  
solution

REF

Use GNSS Rapid solution from CODE as reference

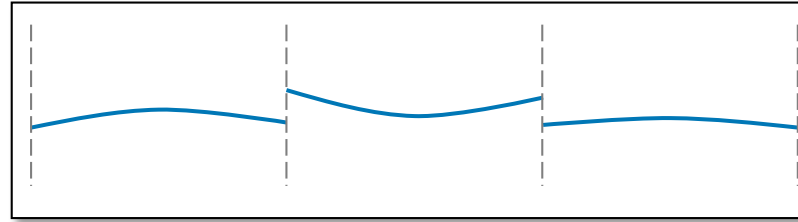
- Using IERS-Bulletin-A as a priori ERP
- Fix first dUT1 value

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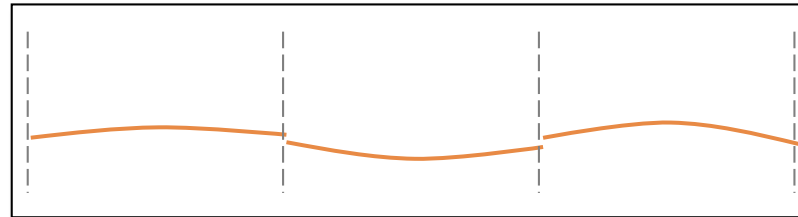
# Orbit validation

- 3 GNSS: GPS | GLONASS | Galileo
- 1-day arcs
- 113 days
- DoY 045-157 2022

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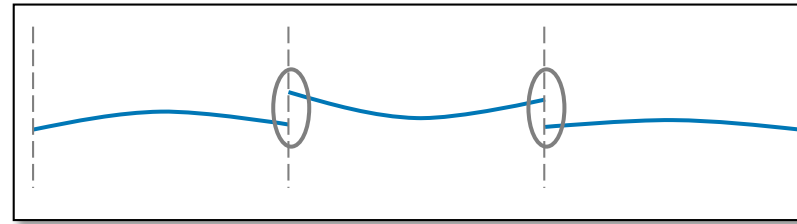
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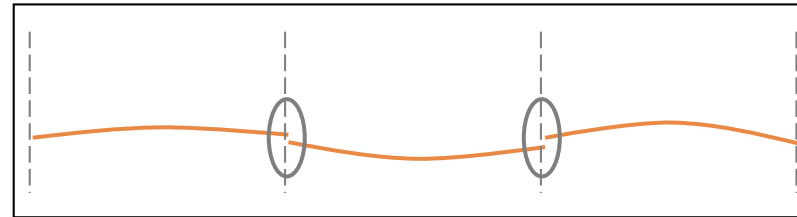
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## Analyse orbit differences at day boundaries

REF



BKG

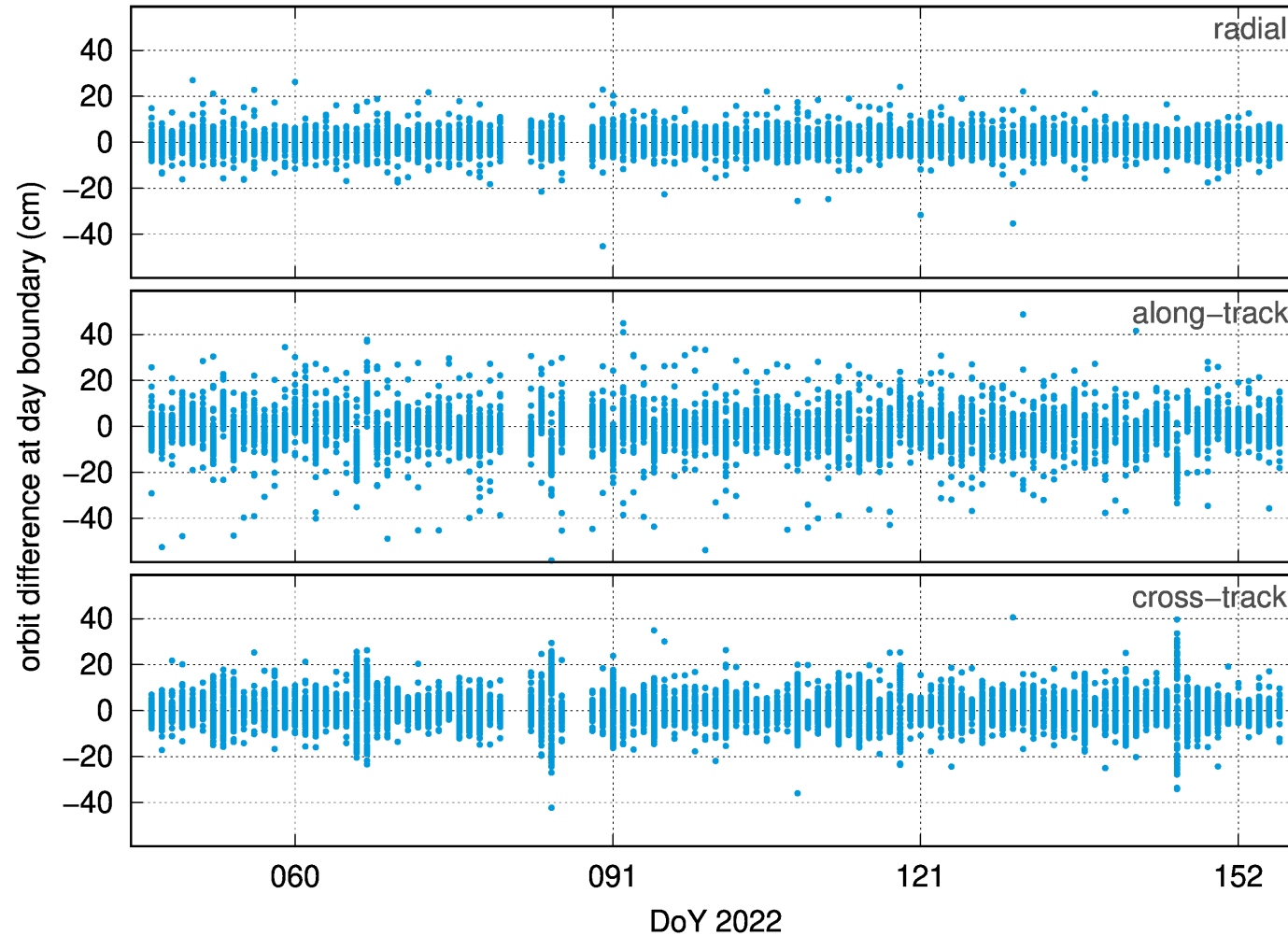


# Satellite-specific orbit differences at day boundaries (1-day arcs)



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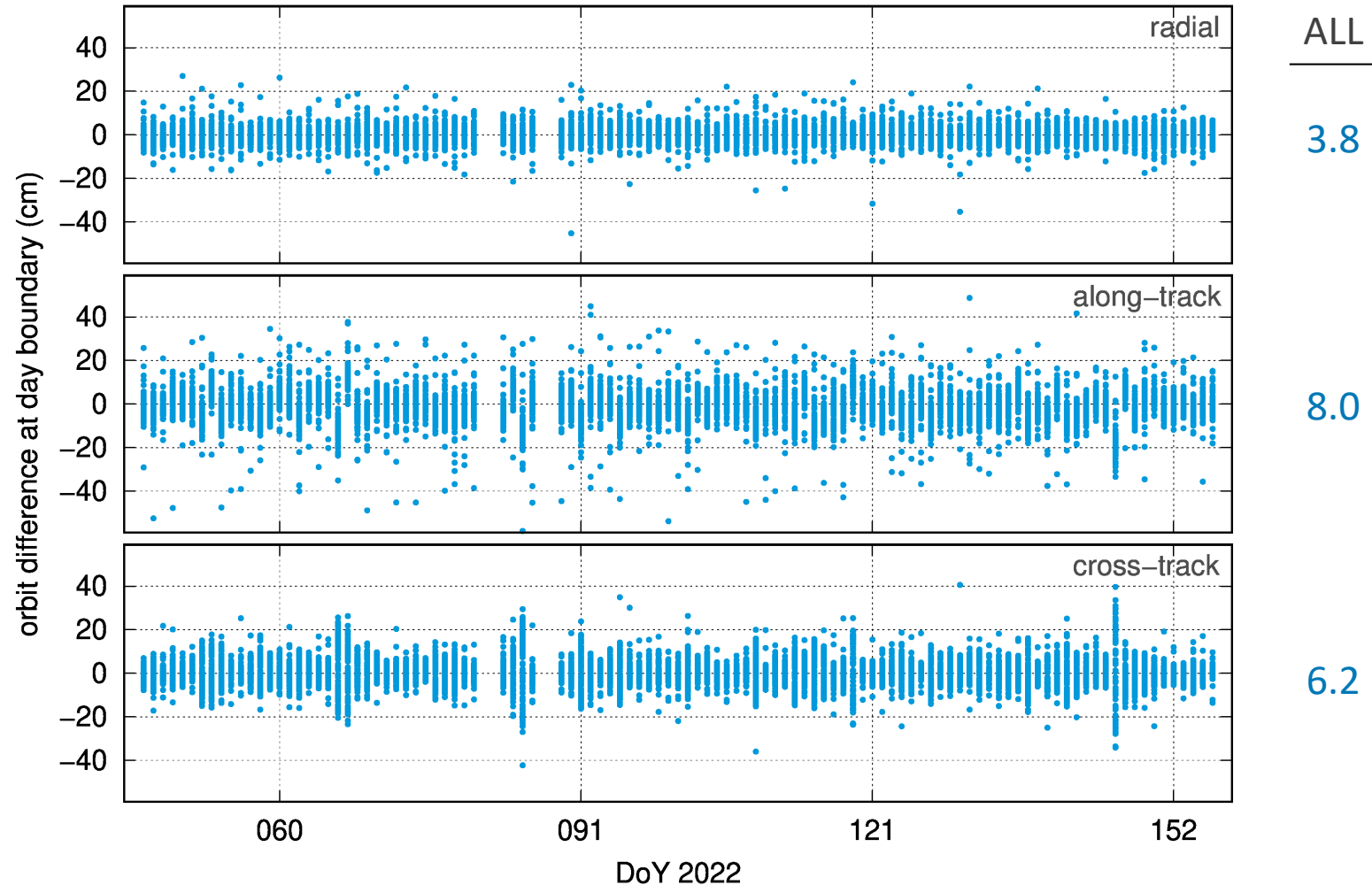
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RMS (cm)

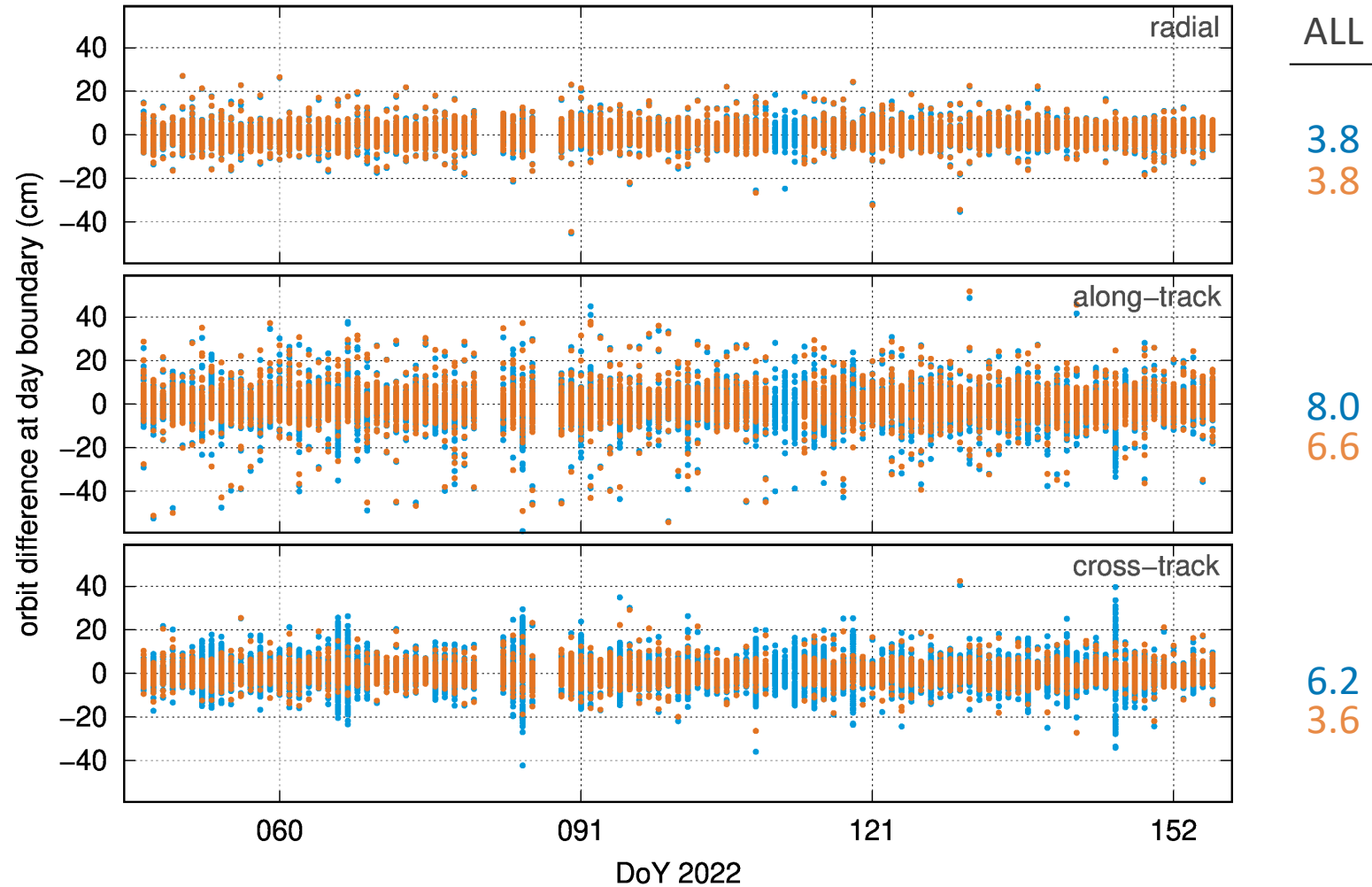
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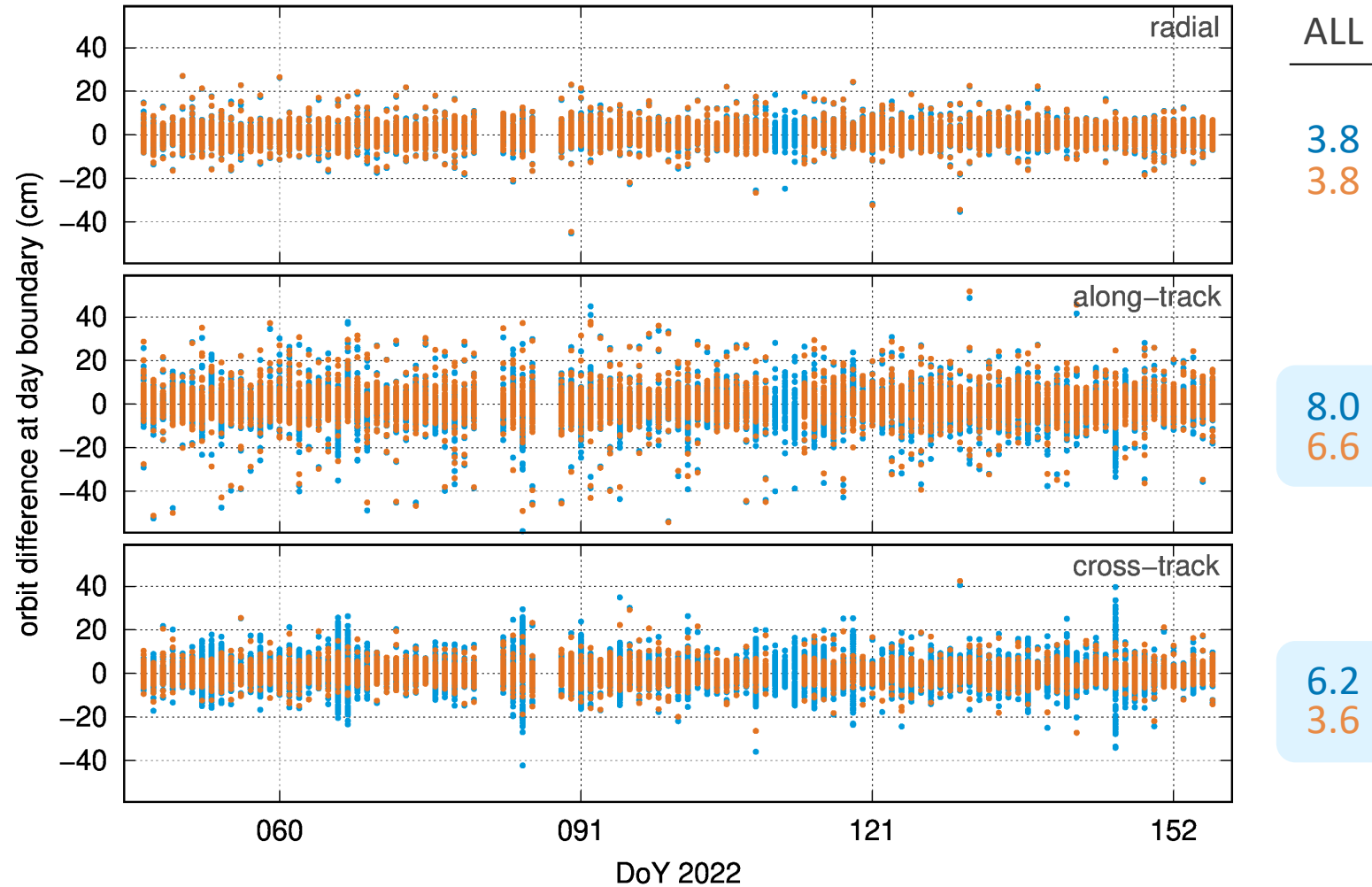




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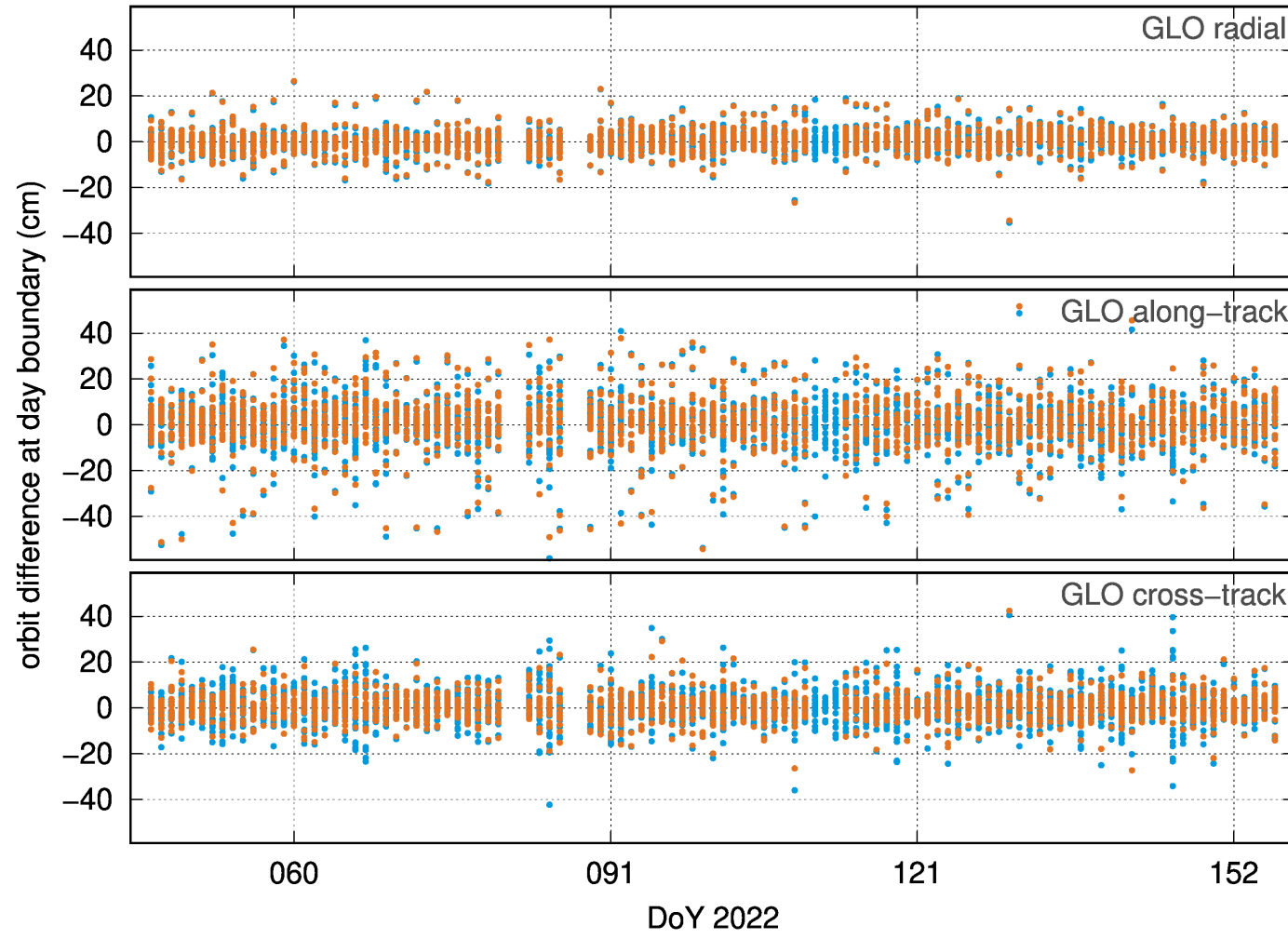


Improvement in  
along-track and  
cross-track

# Satellite-specific orbit differences at day boundaries (1-day arcs)

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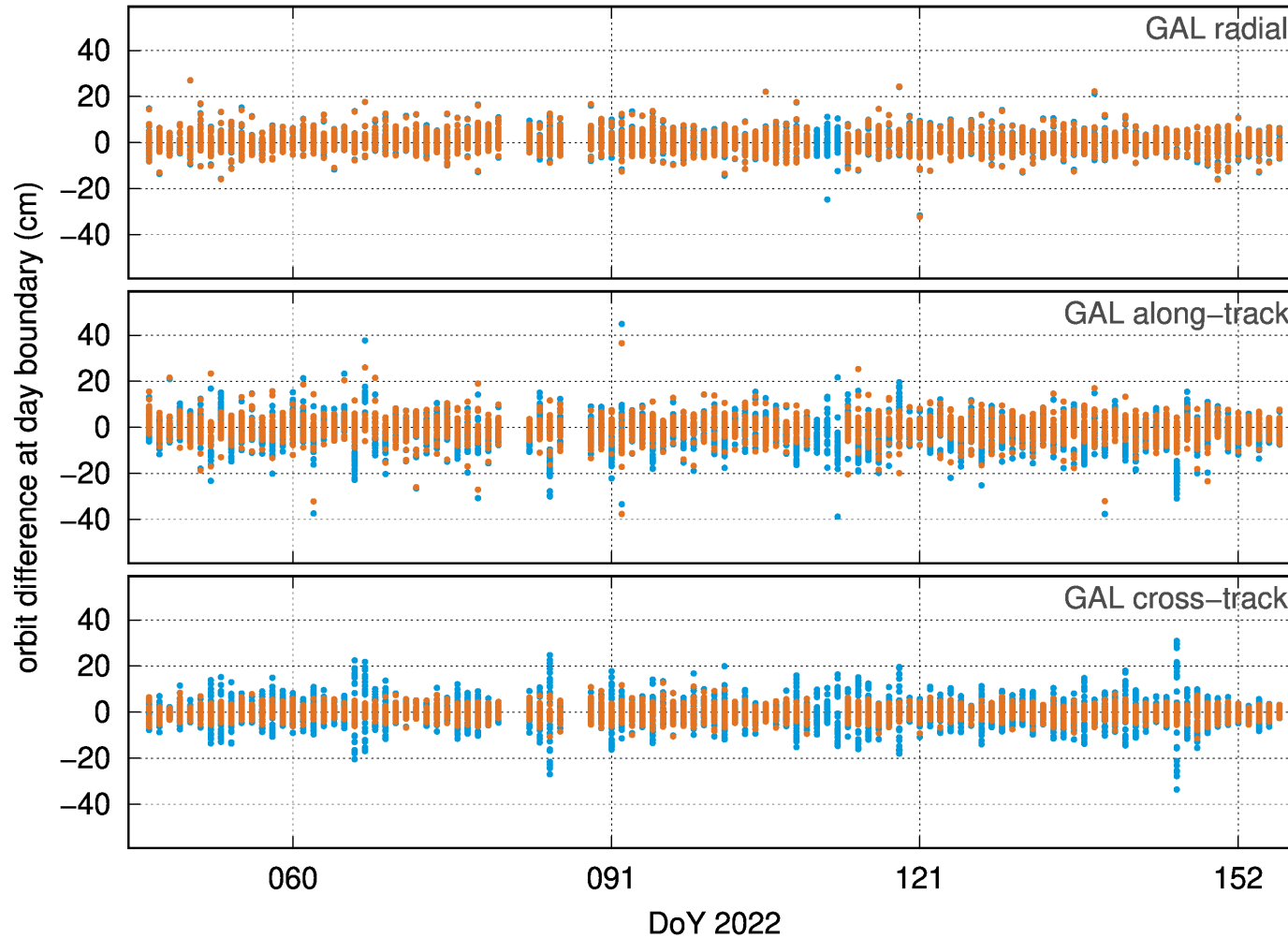


	ALL	GLO
GLO radial	3.8 3.8	4.7 4.7
GLO along-track	8.0 6.6	11.4 10.9
GLO cross-track	6.2 3.6	7.6 5.6

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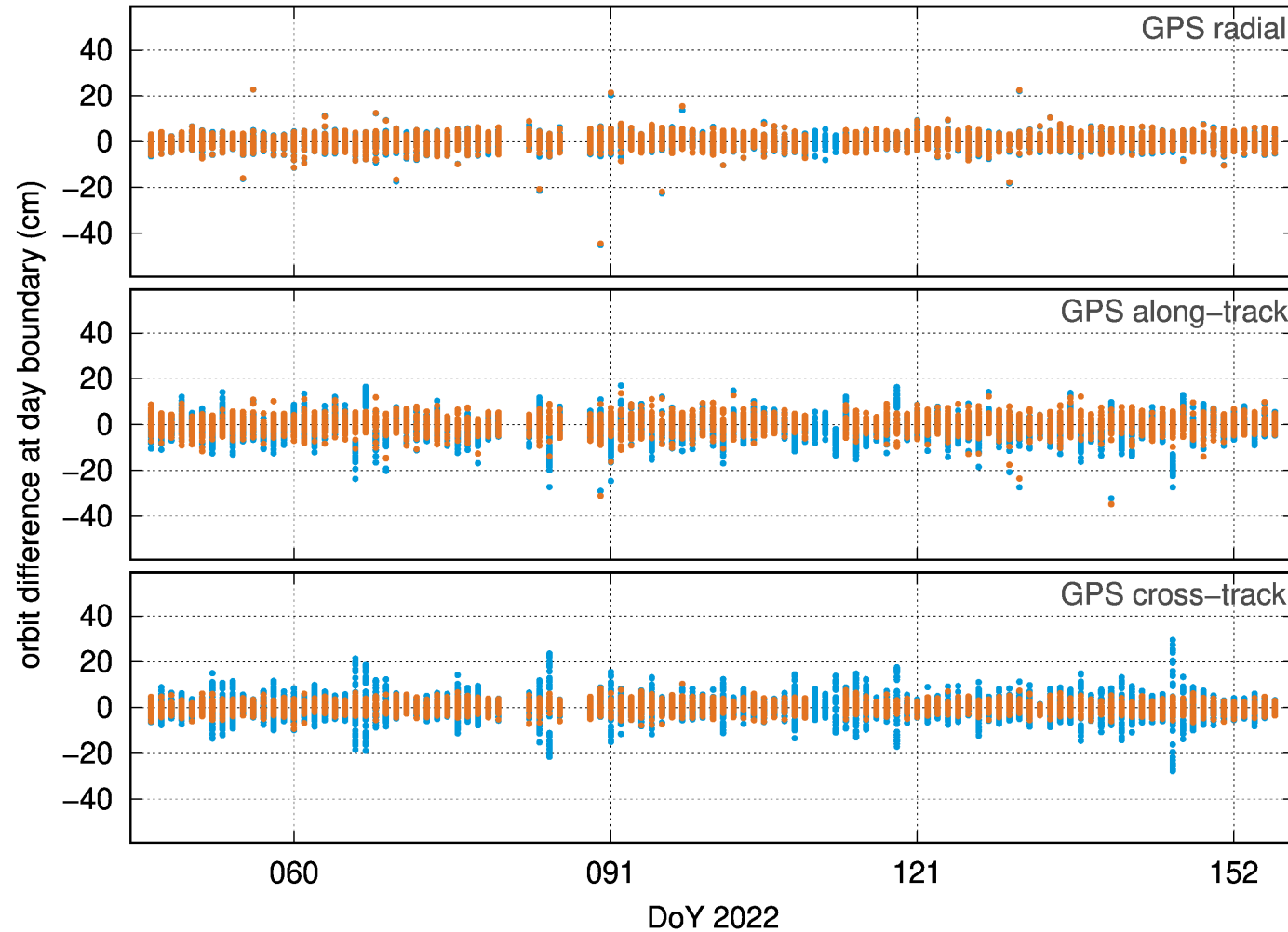


	ALL	GLO	GAL
GAL radial	3.8 3.8	4.7 4.7	4.1 4.1
GAL along-track	8.0 6.6	11.4 10.9	7.4 4.9
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# Conclusions



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Answer: **Improved orbits**

- in along-track and cross-track orbit differences at day boundaries
- for GPS, GLONASS, Galileo
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Solar radiation pressure modelling?  
Plane-specific dependencies?  
Eclipse behavior?  
LOD bias?

..



Federal Agency for  
Cartography and Geodesy



Thank you for your kind attention!



Federal Agency for Cartography and Geodesy (BKG)  
Section G1

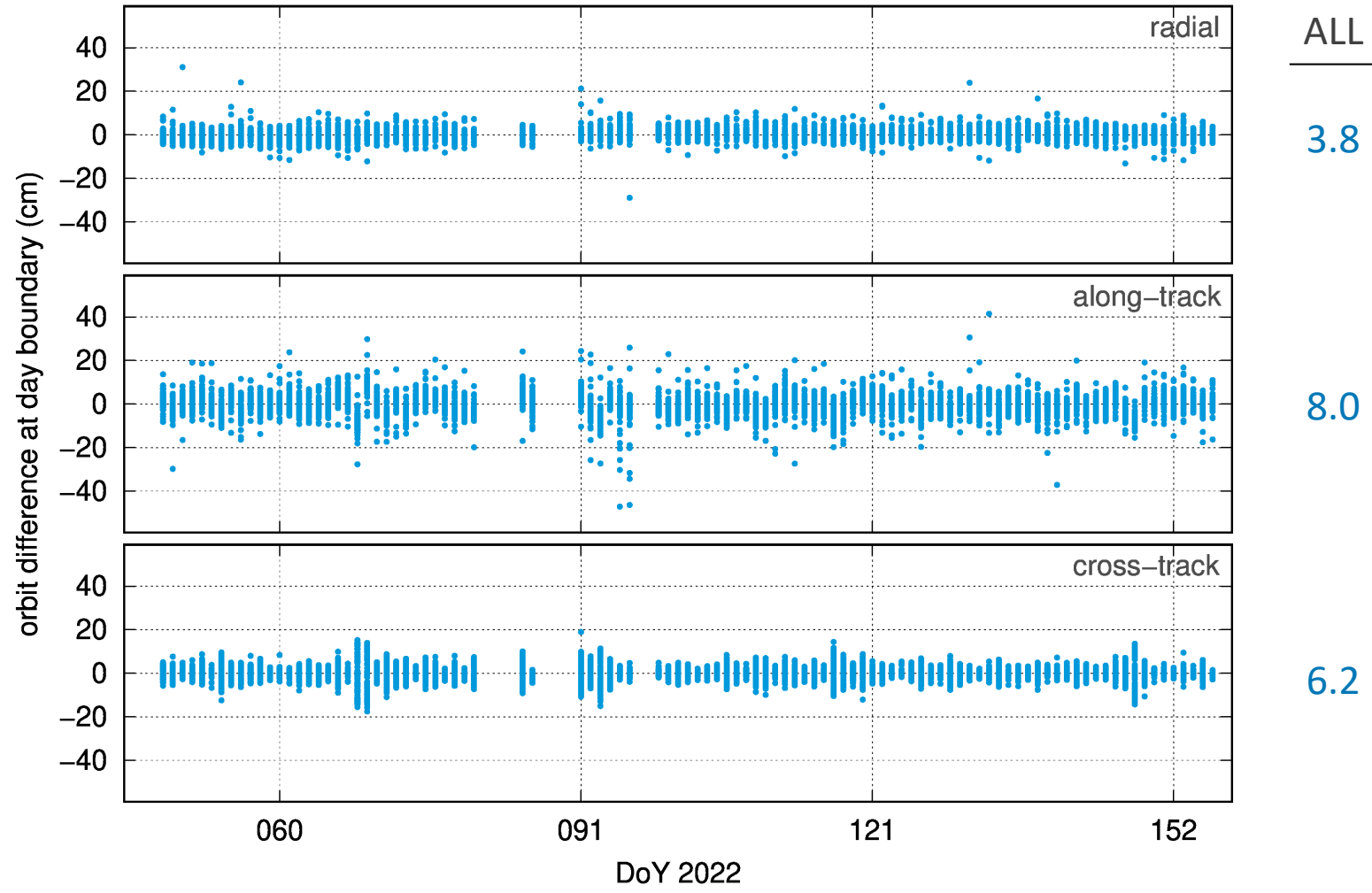
Richard-Strauss-Allee 11  
D-60598 Frankfurt am Main, Germany

Claudia Flohrer, Dr. phil.-nat.  
claudia.flohrer@bkg.bund.de  
www.bkg.bund.de  
Phone +49 69 6333 – 456

# Satellite-specific orbit differences at day boundaries (3-day arcs)

RMS (cm)

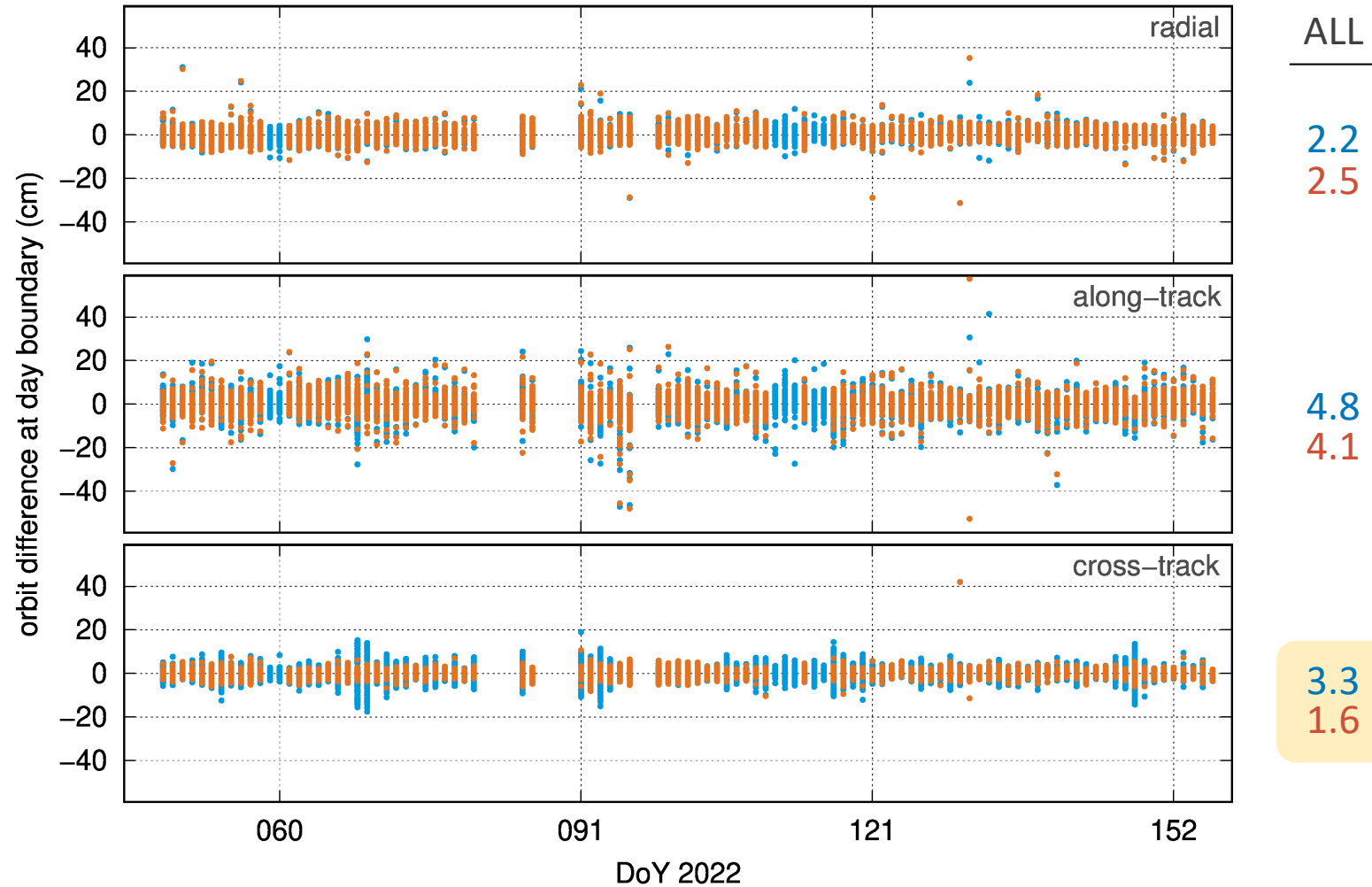
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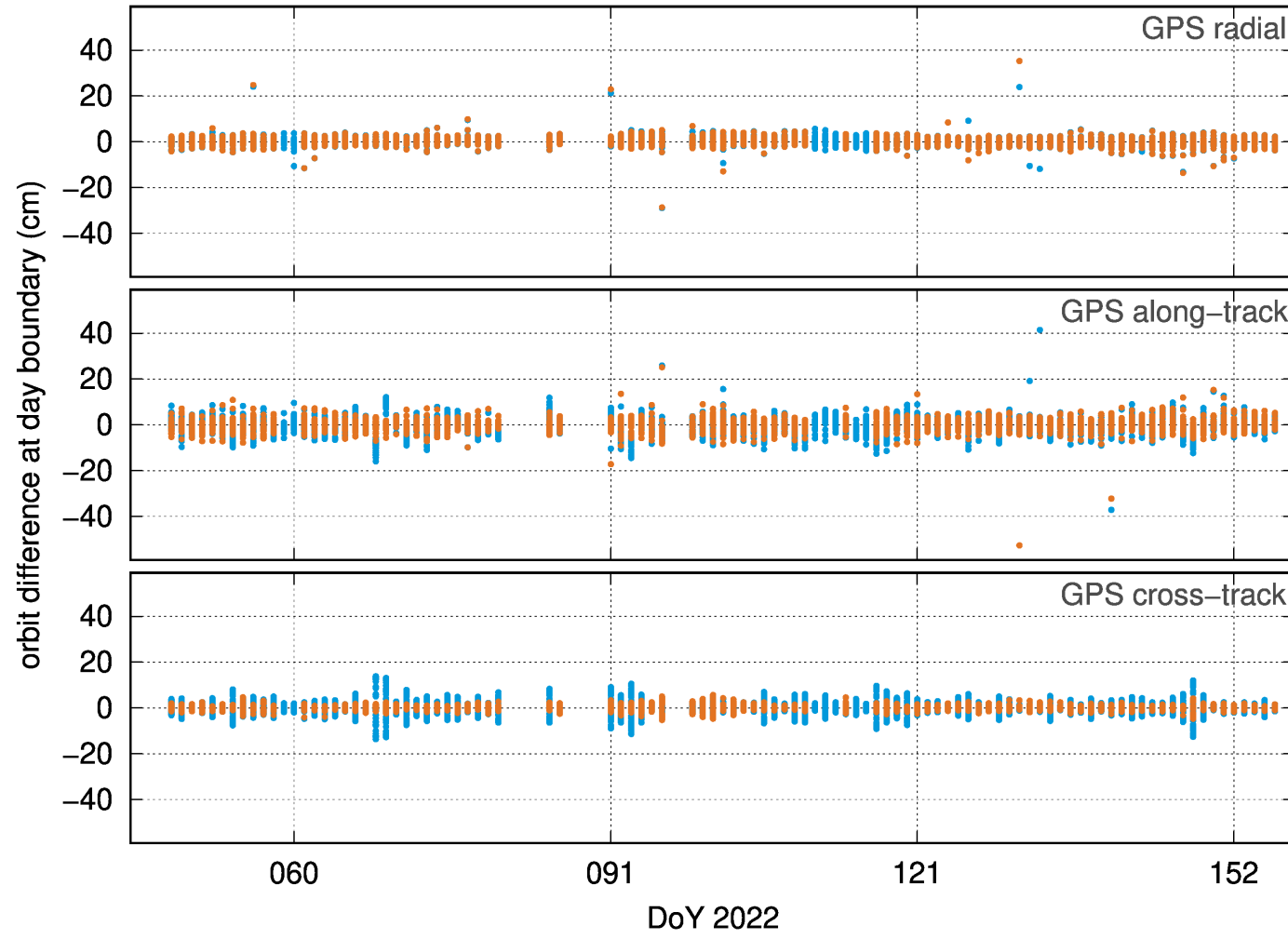
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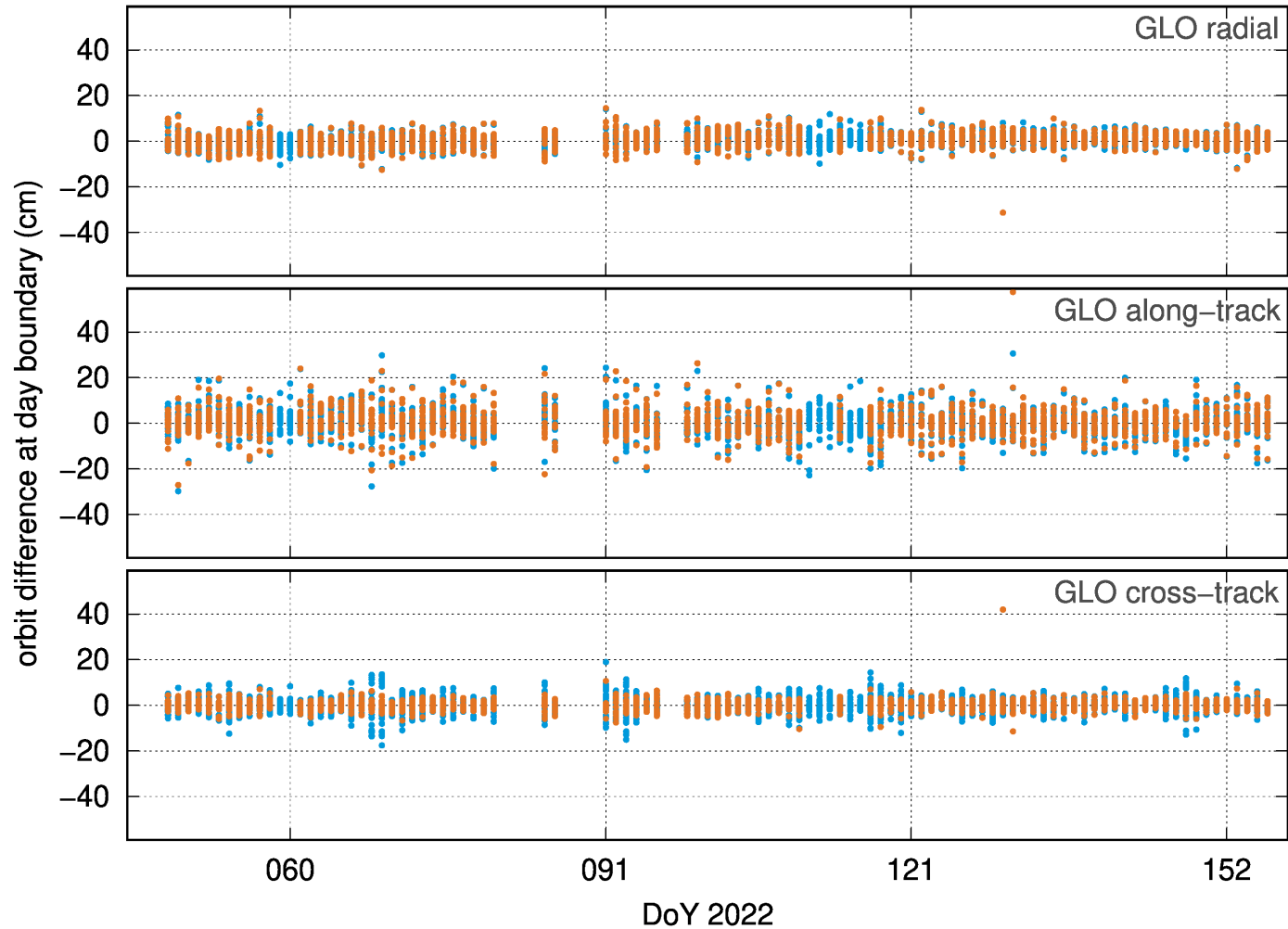


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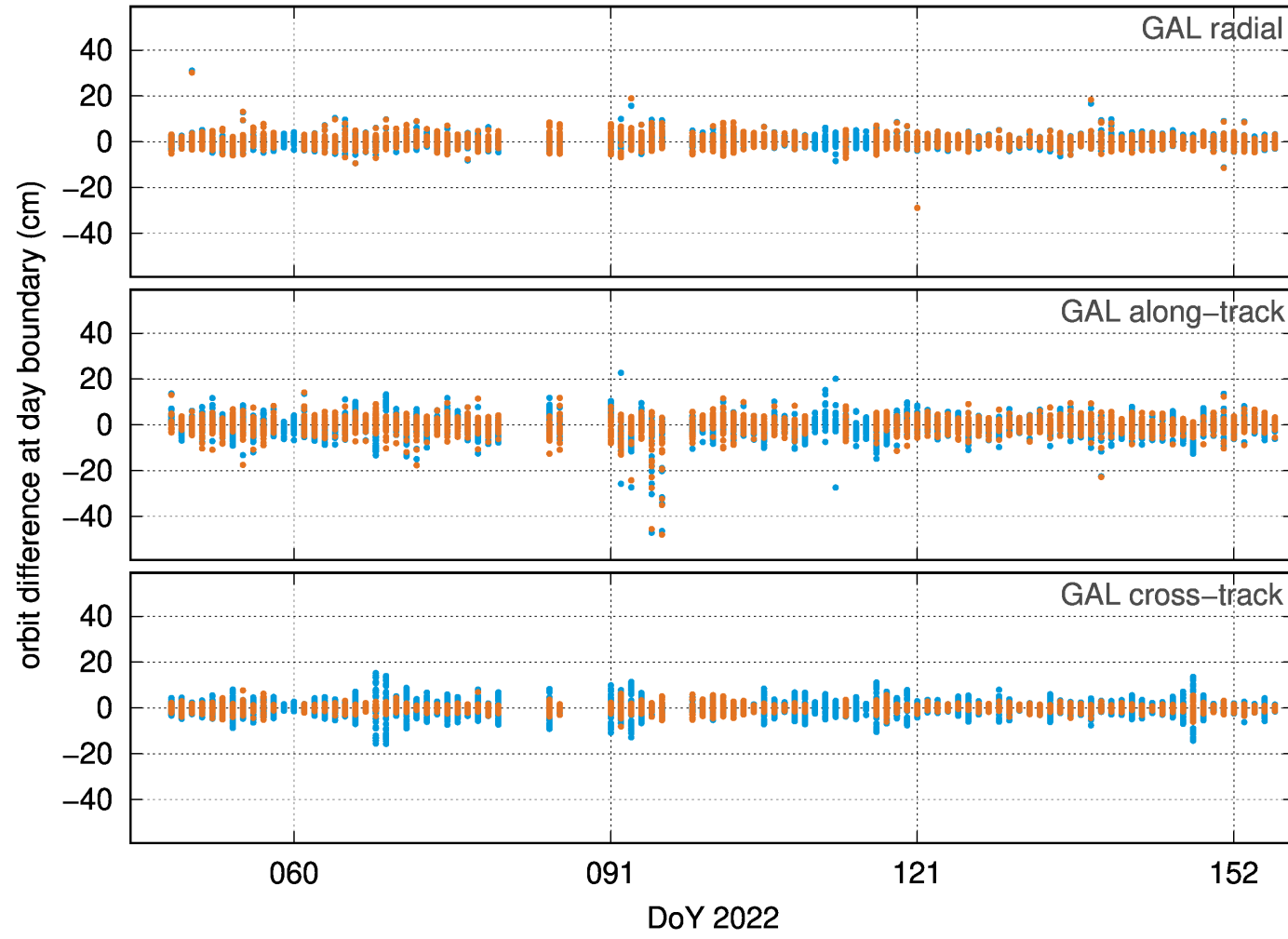
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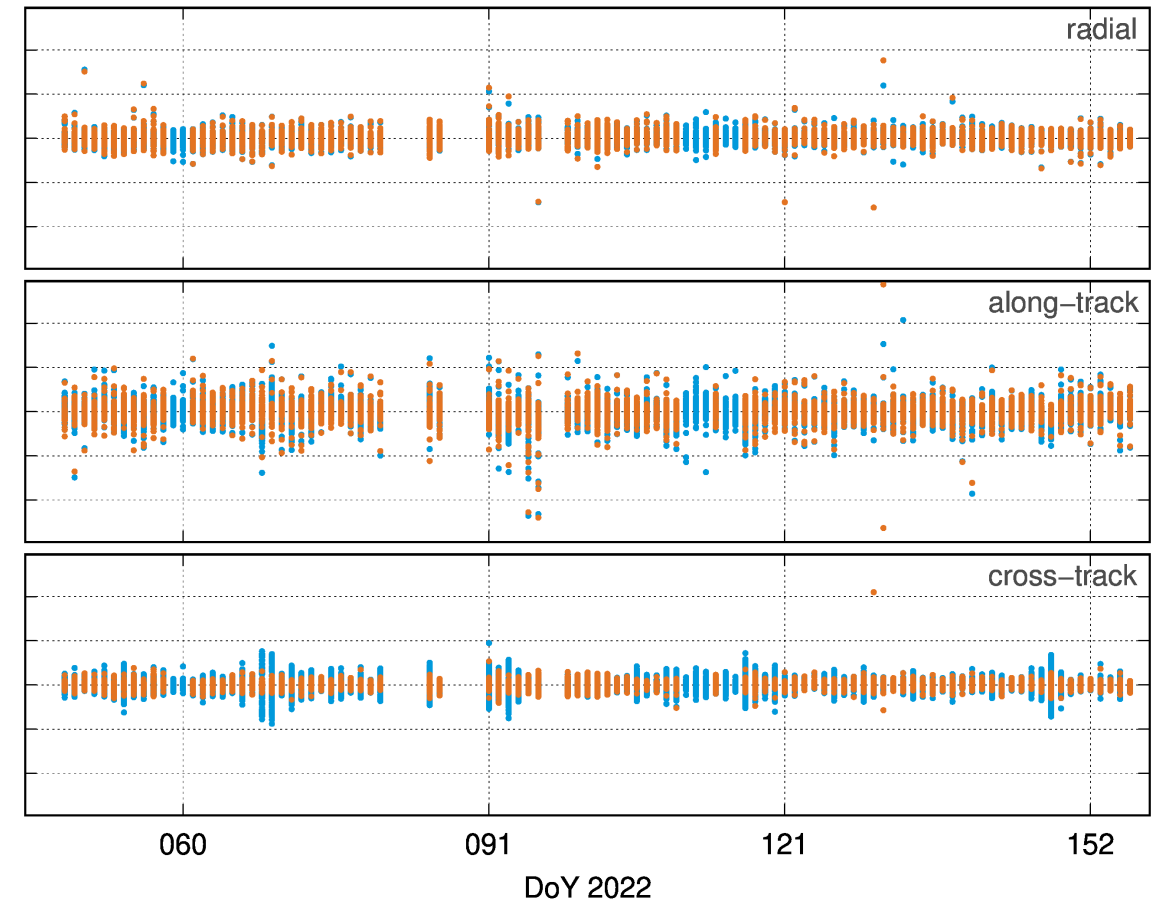
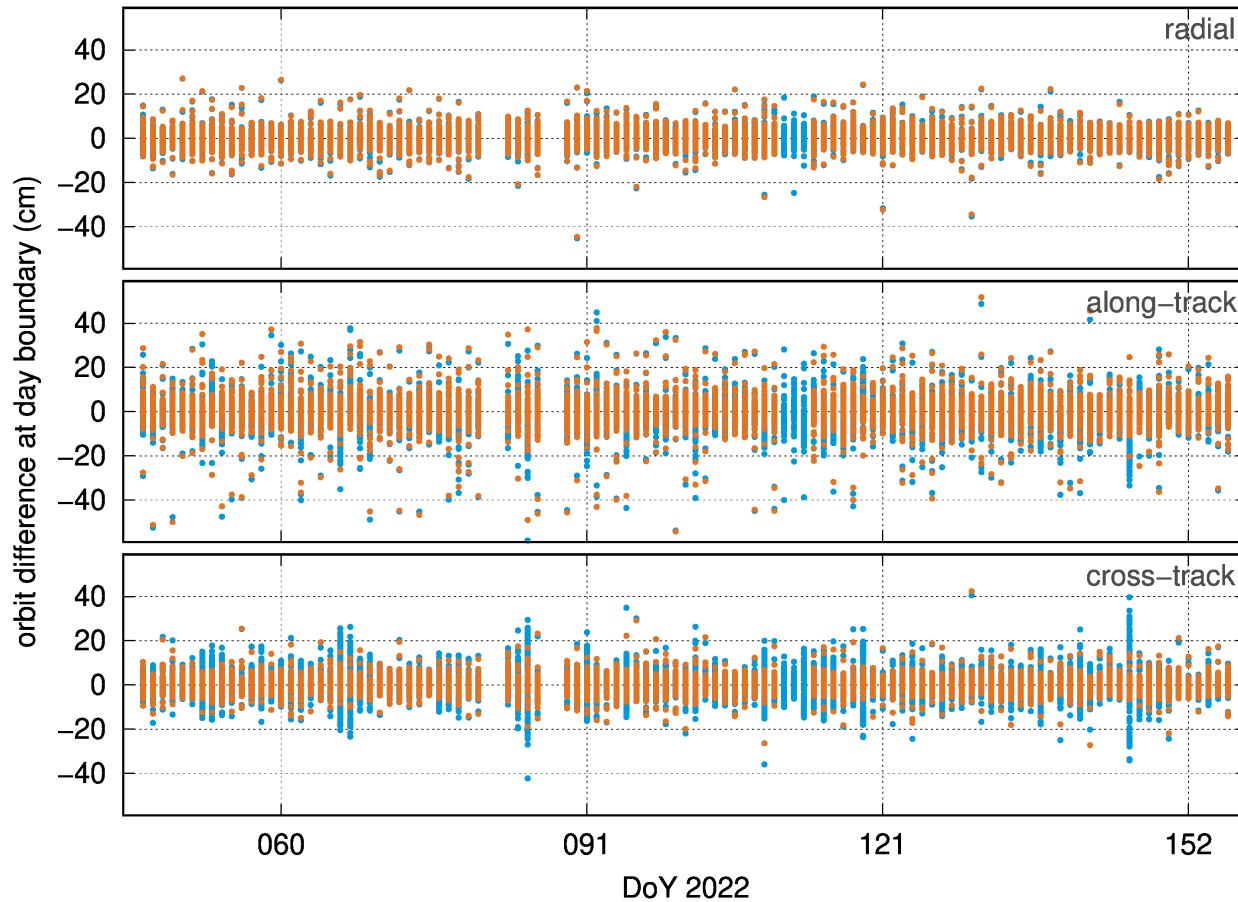
	GPS	GLO	GAL
ALL	1.7	2.9	2.2
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	4.1	6.0	4.8
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	3.1	3.6	3.4
	1.1	2.2	1.5



# Satellite-specific orbit differences at day boundaries

(1-day arcs)

(3-day arcs)



REF

BKG

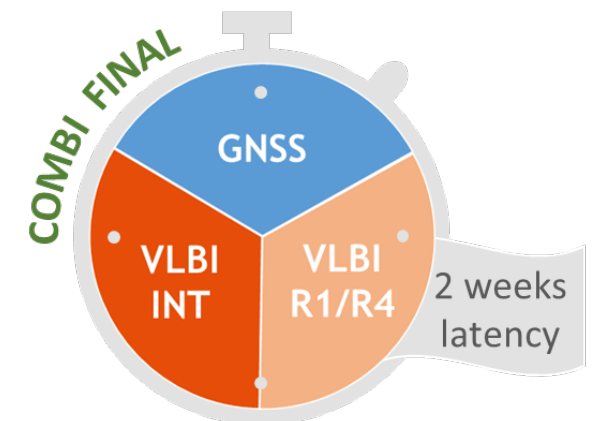
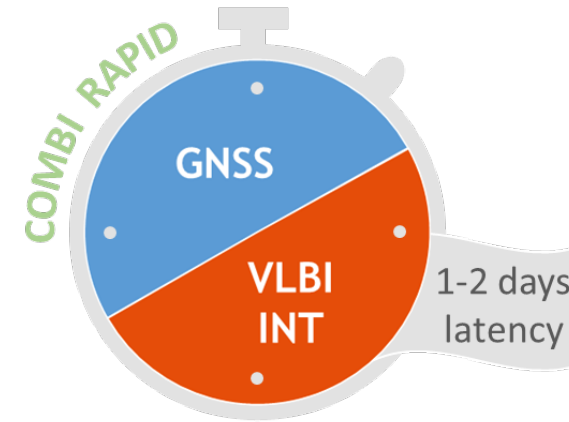
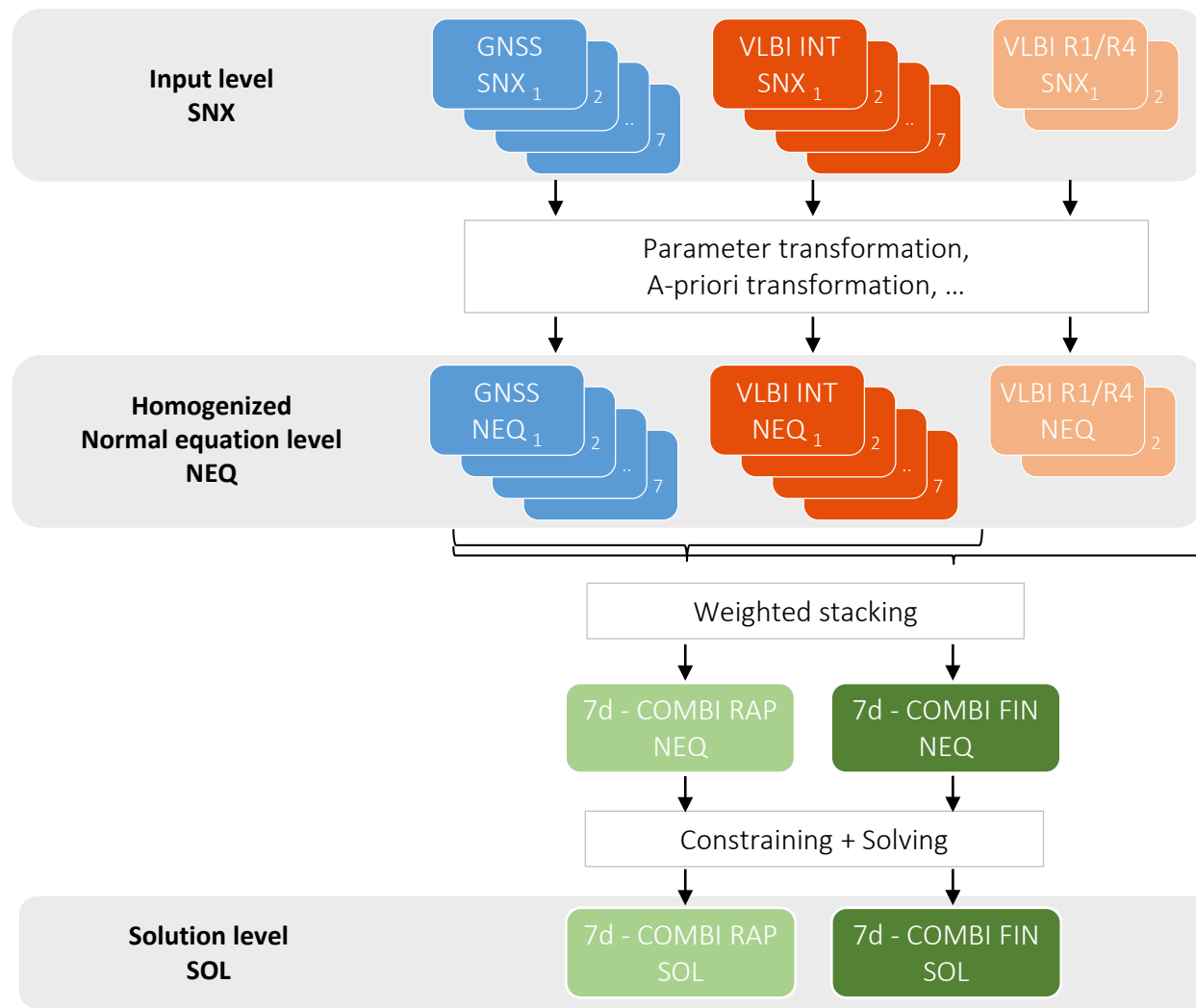
# 2019-2022 (GALILEO ab 2071\_4)

## GNSS LOD Bias – 7-day GNSS single-technique

	Day n	$\mu_{dUT1}$ [ms]	LoD [ms/d] ( $\mu_{dUT1_n} - \mu_{dUT1_{n-1}}$ )
7-day GNSS without LOD bias correction	-6	0.0032	
	-5	0.0093	0.0061
	-4	0.0154	0.0061
	-3	0.0213	0.0059
	-2	0.0275	0.0061
	-1	0.0336	0.0061
	0	0.0396	0.0060
	Day n	$\mu_{dUT1}$ [ms]	LoD [ms/d] ( $\mu_{dUT1_n} - \mu_{dUT1_{n-1}}$ )
7-day GNSS with LOD bias correction of <b>6.1<math>\mu</math>s</b>	-6	0.0002	
	-5	0.0003	0.0001
	-4	0.0008	0.0005
	-3	0.0010	0.0002
	-2	0.0014	0.0004
	-1	0.0018	0.0004
	0	0.0025	0.0007

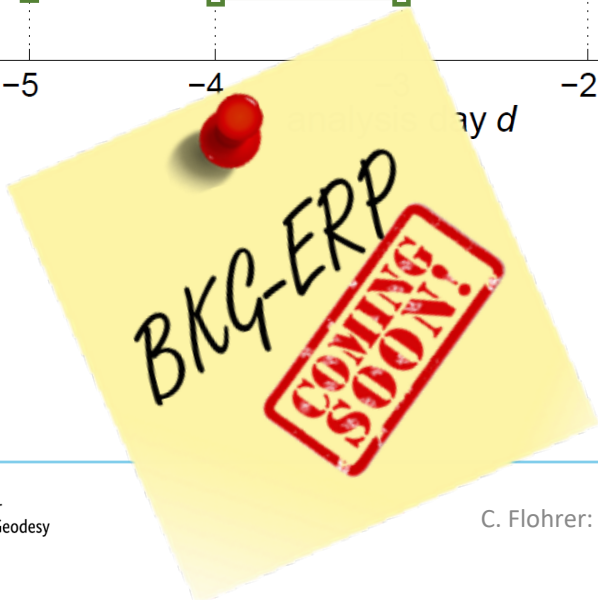
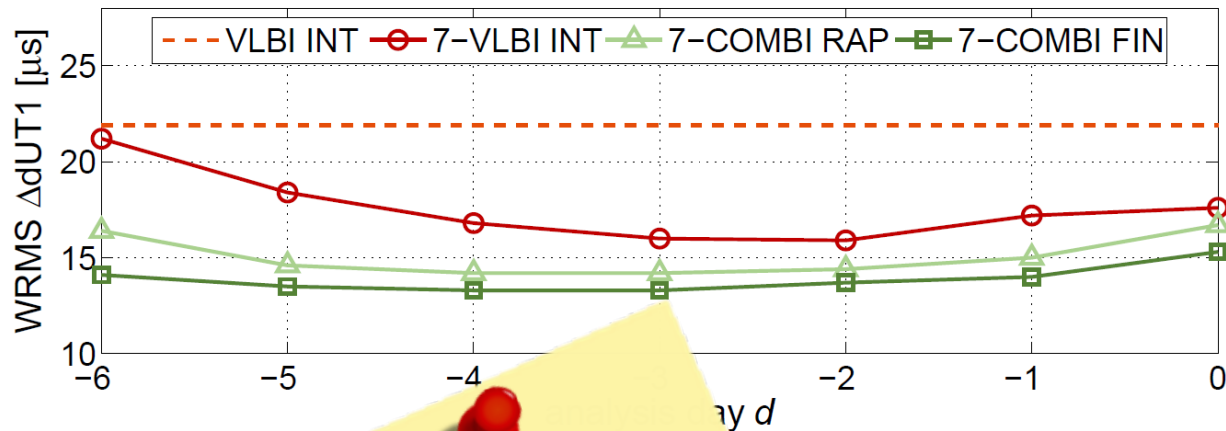
<b>GNSS RAP CODE (72h session)</b>			
explicit	Station coordinates		constant offset
	ERP	Pole coordinates	PWL offsets every 24h (4/72h)
		dUT1	PWL offsets every 24h (4/72h)
	Geocenter Satellite PCO	Z-direction	constant offset constant offset
implicit	Satellite orbit	Keplerian elements Dynamical parameter	constant offsets in D-, Y-, and B-direction periodic 1pr in B-direction periodic 2pr in D-direction
		Stochastic pulses	small velocity changes every 12h in radial along-track and out-of-plane direction
	Troposphere	ZWD Gradients	PWL offsets every 2h for each station constant offsets for 24h
<b>VLBI INT BKG (1h session)</b>			
explicit	Station coordinates		constant offset
	ERP	Pole coordinates	constant offset
		Pole rates	drift
		dUT1	constant offset
		LOD	drift
implicit	Source coordinates		constant offset
	Troposphere	ZWD	constant offset for each station
	Station clocks		quadratic polynomial for each station

# Combination Scheme – 7-day Combination of VLBI and GNSS



# Results – 7-day Combination of VLBI and GNSS

Validation epoch: **12:00 UTC**  
Reference series: **IERS-Bulletin-A**



## 7-day VLBI INT

- significant reduction of the WRMS values
- no constraining of the LOD is required
- improves accuracies outside the INT observation period

## 7-day COMBI RAPID

- significant reduction of the WRMS values
- polar motion and LOD from GNSS complements dUT1 from VLBI INT
  - daily, consistent and regularly spaced high-precision ERP
  - short latency of 1-2 days

## 7-day COMBI FINAL

- significant reduction of the WRMS values, especially at the boundary days of the 7-day polygon (d = 0, -6)
- stabilization of all ERP through 24h VLBI R1/R4 twice a week
  - daily, consistent and regularly spaced high-precision ERP including the celestial pole offsets
  - latency of 14 days